Measurements of strange and non-strange charm production in PbPb collisions at 5.02 TeV with the CMS detector

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Strangeness in Quark Matter 2019
Motivation

- Heavy quarks produced early, experience the full evolution of the medium

- $D^0 R_{AA}$: nuclear modification factor
  - Flavor dependent energy loss

- $D^0 \nu_n$ harmonics in PbPb:
  - At low $p_T$, the degree of medium thermalization
  - At high $p_T$, the path length dependence of energy loss

- $D^0$ elliptic flow $\nu_2$ in high multiplicity pPb
  - Evidence of QGP in small system?
  - Heavy flavor hydrodynamic flow?
D Meson Reconstruction & Selection

- $D^0 \rightarrow K\pi^+ \; BR = 3.89\% \; c\tau \approx 120 \, \mu m$

- $D^0$ candidates :
  - pairing two charged tracks
  - kinematic fitter

- $D^0$ candidates selection (Rectangular Cuts optimized using TMVA)
  - Pointing angle $\alpha < 0.12 - 0.15$
  - 3D decay length significance $> 3.0 - 4.8$
  - $D^0$ candidate vertex probability $> 0.05 - 0.25$
  - Distance of Closet Approach (DCA) $< 0.008 \, \text{cm} \; (\text{in } \nu_\tau \text{ analysis })$
D⁰ Signal Extraction by Invariant Mass Fit

D⁰ invariant mass distributions are fitted by

- **Double Gaussian (Signal)**
- **3rd order polynomial (Combinatorial)**
- **Single Gaussian (K-π swapped. No PID. Candidates with wrong mass assignment on tracks)**

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**PLB 782,474(2018)**
• $D^0$ in data is a mixture of prompt and non-prompt $D^0$

• Fit DCA of data with prompt and non-prompt $D^0$ DCA MC templates

PLB 782,474(2018)
**$D^0$ $R_{AA}$ and Comparison with Model Calculations**

Charm quarks lose a significant fraction of energy in the QGP medium.

- $R_{AA}$ minimal near $p_T \sim 10$ GeV/c and then increases.
- At high $p_T$, both pQCD and AdS/CFT predictions reasonably agree with $R_{AA}$ results.
- At low $p_T$, PHSD with shadowing describes data better.

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**Graphical Representation**

- ** CMS**
  - $D^0 + \bar{D}^0$
  - $R_{AA}$
  - $|y| < 1$
  - Cent. 0-10%
  - $p_T$ (GeV/c)

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**References**

- PLB 782,474(2018)
- SQM 2019

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**Author**

Cheng-Chieh Peng
At low $p_T$, a hint of smaller suppression of $D^0$ and non-prompt $J/\psi$ than charged particles.

At high $p_T$, the $D^0 R_{AA}$ is similar to charged particles $R_{AA}$.

The non-prompt $J/\psi$ appear to be less suppressed than the D for $p_T$ smaller than $\sim 15$ GeV.

References:

- JHEP 04(2017)39
- PRL 119, 152301(2017)
- PLB 782, 474(2018)
- EPJC 78 (2018) 509
$\mathbf{D^0} \; \nu_n$ in PbPb collisions at 5.02 TeV

- $\nu_n$ obtained by scalar product method

(Luzum, Ollitrault PRC 87 (2013), 044907)

- Simultaneous fit on mass distribution and $\nu_n$ vs. mass

\[
\nu_n^{S+B}(m) = \alpha(m)\nu_n^S(m) + [1 - \alpha(m)]\nu_n^B(m)
\]

\[
\alpha(m) = \frac{\text{Sig}(m) + \text{Swap}(m)}{\text{Sig}(m) + \text{Swap}(m) + \text{Bkgd}(m)}
\]

PRL 120,202301(2018)
Positive prompt $D^0 \nu_2$ is observed:

- Low $p_T$ : charm quark collective motion
- High $p_T$ : path length dependence of energy loss

Similar $p_T$ dependence to charged particle

At centrality 10-30% and 30-50% , the $\nu_2(D^0) < \nu_2$(charged particle)

Mass ordering or other effect?
Prompt $D^0 \nu_3$ Result

CMS PbPb $\sqrt{s_{NN}} = 5.02$ TeV

- $D^0$, $|y| < 1.0$
- Charged particle, $|\eta| < 1.0$

- Low $p_T$: $\nu_3$ (prompt $D^0$) $> 0$; Hight $p_T$: $\nu_3$ (prompt $D^0$) $\approx 0$
- Similar $p_T$ dependence to charged particle

PRL 120,202301(2018)
Prompt $D^0 \nu_3$ Result

- Low $p_T$ : $\nu_3$ (prompt $D^0$) $> 0$; High $p_T$ : $\nu_3$ (prompt $D^0$) $\approx 0$
- Similar $p_T$ dependence to charged particle
- Little centrality dependence
  - Indicate a constant initial geometry
- $\nu_2$ and $\nu_3$ results provide constrain on models
D⁰ ν₂ in pPb Collisions at 8.16 TeV

- Two-particle correlation method to extract ν₂
  - Correlate D⁰ and charged hadrons (|Δη| gap = 1)
  - Perform Fourier fits the two particle correlation

\[ ν²_{D⁰}(p_T) = \frac{V_{2Δ}(p_T^{D⁰}, p_T^{assoc})}{\sqrt{V_{2Δ}(p_T^{assoc}, p_T^{assoc})}} \]

- D⁰ ν₂^{sub}, to reduce the non-flow contributions
  - subtracting the V₂Δ in low multiplicity (Ntrk <35)

- Simultaneous fit on mass distribution and ν₂ vs. mass

PRL 121,082301(2018)
D⁰ Meson and Strange Hadrons $v_2$ vs $p_T$

- Significant $D^0$ $v_2$ have been observed in high multiplicity pPb

$\nu_2^{D^0} < \nu_2^{\text{strange hadrons}}$

PRL 121,082301(2018)
**D⁰ Meson 𝜈₂ vs 𝑝ₜ and PbPb Collisions**

- **pPb**
  - 185 ≤ N_{offline} < 250
  - -1.46 < y_{cm} < 0.54

- **PbPb**
  - Centrality 30-50%
  - ⟨N_{offline}⟩ = 919
  - -1 < y_{cm} < 1

- \( D⁰ \, 𝜈₂^{pPb} < 𝜈₂^{PbPb} \) for a given \( pₜ \)

- Similar mass ordering for pPb and PbPb

**PRL 121,082301(2018)**
Number of constituent quarks (NCQ) scaling is motivated by quark coalescence model

In pPb, \( D^0 \) \( v_2/n_q \) is smaller than strange hadrons for \( KE_T/n_q < 2 \)

In PbPb, \( D^0 \) \( v_2/n_q \) follow the same trend as other particle species
Summary

- **$D^0 R_{AA}$ at 5.02 TeV PbPb**
  - Strong suppression of $D^0 R_{AA}$
  - $R_{AA}(D^0) \sim R_{AA}(h^{\pm})$ at high $p_T$
  - $R_{AA}(D^0) > R_{AA}(h^{\pm})$ at low $p_T$

- **$D^0 \nu_2$ at 8.16 TeV pPb**
  - Significant $\nu_2$ in high multiplicity events
  - $\nu_2(D^0) < \nu_2$ (strange hadrons)
The CMS Trigger and Data Sets

Data sets

• LHC Run II 2015 pp and PbPb at $\sqrt{s_{NN}} = 5.02$ TeV and 2016 pPb data at $\sqrt{s_{NN}} = 8.16$ TeV
• Minimum bias sample for $p_T < 20$ GeV/c and triggered samples for $p_T > 20$ GeV/c
• Dedicated HLT D meson filters to enhance the statistics of very high $p_T$ D mesons
• High multiplicity trigger to select high multiplicity pPb events comparable to peripheral PbPb

Triggering system

Hardware Level 1
Jet Trigger Selections

Track Selections
in Software Triggers

$D^0$ Selections

Level 1 (L1) jet algorithm with online background subtraction

Track seed $p_T$ cut applied:
- $p_T > 2$ GeV/c for pp/pPb
- $p_T > 8$ GeV/c for PbPb

$D^0$ online reconstruction
Loose selections based on $D^0$ vertex displacement
Scalar Product Method

\[ Q_n = \sum_j w_j e^{in\phi_j} \]

Sum over tracks (tracker), or towers (HF)

\( w_j \): tower \( E_T \) for HF, track \( p_T \) for tracker

\[ v_n \{SP\} = \frac{\langle Q_n \cdot Q_n^* \rangle}{\sqrt{\langle Q_{nA} \cdot Q_{nA}^* \rangle \langle Q_{nB} \cdot Q_{nB}^* \rangle \langle Q_{nC} \cdot Q_{nC}^* \rangle}} \]

Scaling factor from 3 sub events

- Large \( \eta \) gap applied (\(|\Delta\eta|>3.0\))
- \( v_n \{SP\} \), non-ambiguous measure of \( \sqrt{v_n^2} \)

Luzum, Ollitrault PRC 87 (2013), 044907
• Fourier series describing the azimuthal anisotropy of particle spectrum
\[
\frac{dN}{d\phi} \propto 1 + \sum 2\nu_n(p_T, \eta)\cos[n(\phi - \psi_n)]
\]

• Two-particle correlation method to extract \( \nu_2 \)
  – Correlate \( D^0 \) and charged hadrons (\( \Delta\eta \) gap = 1)
  – Perform Fourier fits the two particle correlation distribution for \( D^0 \) to extract \( V_{2\Delta}(p_T^{D^0}, p_T^{assoc}) \)
  – \( D^0 \nu_2(p_T) \) can be obtain by :
\[
\nu_2^{D^0}(p_T) = \frac{V_{2\Delta}(p_T^{D^0}, p_T^{assoc})}{\sqrt{V_{2\Delta}(p_T^{assoc}, p_T^{assoc})}}
\]